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# **Characterizing Digital Camera Systems: A Prelude to Data Standards**

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**April 24, 2002**



# Outline

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- **Digital Imaging Systems**
- **Specifying a Digital Imagery Product**
- **Characterization of Data Acquisition Systems**
- **Summary**



# Introduction

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- **Advanced large array digital imaging systems are routinely being used**
- **Digital imagery guidelines are being developed by ASPRS and ISPRS**
- **Guidelines and standards are of little use without standardized characterization methods**



# Digital Imaging Systems

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**Both pushbroom line scanners and advanced framing direct digital imaging systems are being developed for airborne and spaceborne systems**

- IKONOS
- QuickBird
- Kodak 4kx4k
- LH Systems
- Z/I
- Others



# Specifying a Digital Imagery Product

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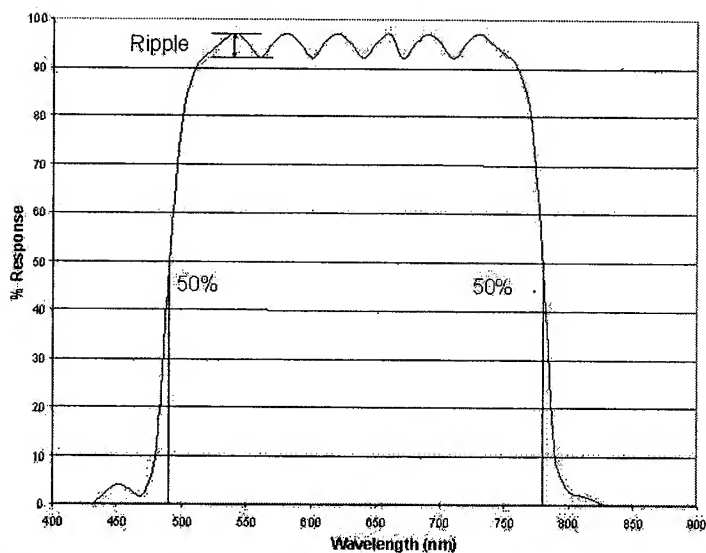
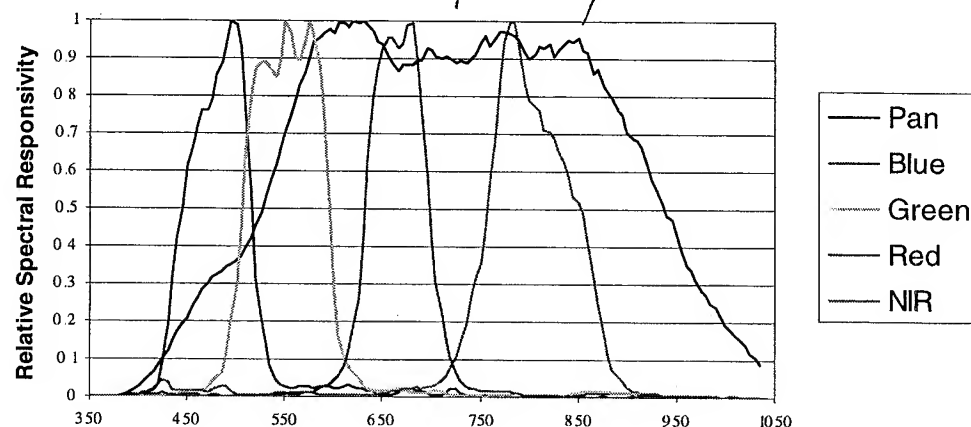
- After the acquisition area and window have been selected the following properties need to be defined
  - Spectral
    - Panchromatic or Multispectral (number of bands)
    - Band-to-Band Registration
  - Spatial Resolution
    - Spatial/Frequency Domain
    - Edge response
    - Signal-to-Noise Ratio
  - Radiometry
    - Linearity
    - Cosmetic/Relative
    - Absolute
  - Geolocational Accuracy
- The ASPRS Digital Imagery Guideline addresses many of these items



# Spectral Characteristics: Bands

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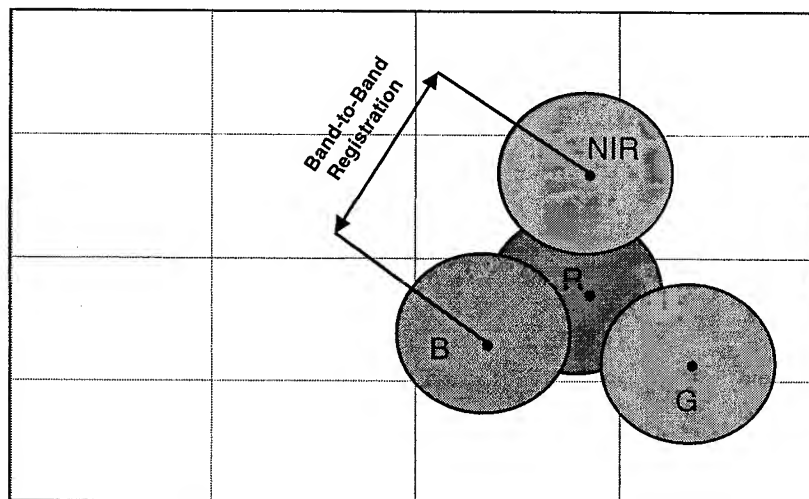
*step*  
IKONOS Relative Spectral Response



$\lambda_{\text{cut-on}}$  50% (spectral response)  $\pm 10$  nm  
Slope @ 50% > 1% / nm

$\lambda_{\text{cut-off}}$  50% (spectral response)  $\pm 10$  nm  
Slope @ 50% > 1% / nm

System spectral response



Band-to-band registration



# Spatial Resolution: Spatial/Frequency Domain

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- **Most specifications are written in terms of MTF as a function of spatial frequency**
  - Dominant parameter is typically MTF @ Nyquist frequency
  - Nyquist frequency depends on GSD
    - $\text{Nyquist frequency} = 1/(2 \cdot \text{GSD})$
  - MTF at Nyquist is a measure of aliasing
  - MTF measurements at Nyquist are difficult to estimate in-flight
- **Edge Response is more intuitive**
  - RER (Relative Edge Response)
  - Ringing

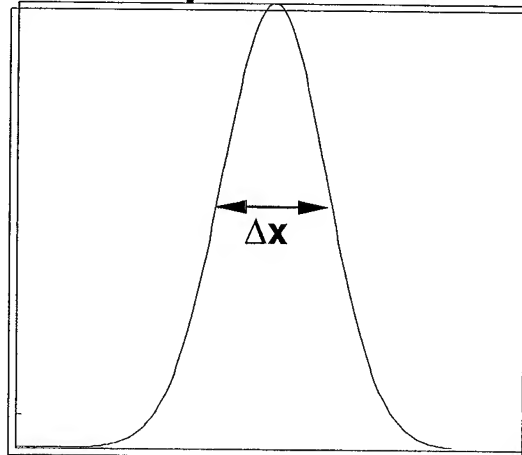


# Spatial Resolution: Edge Response

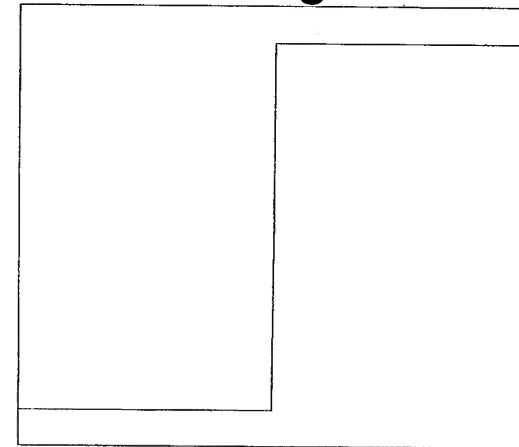
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Spatial  
Domain

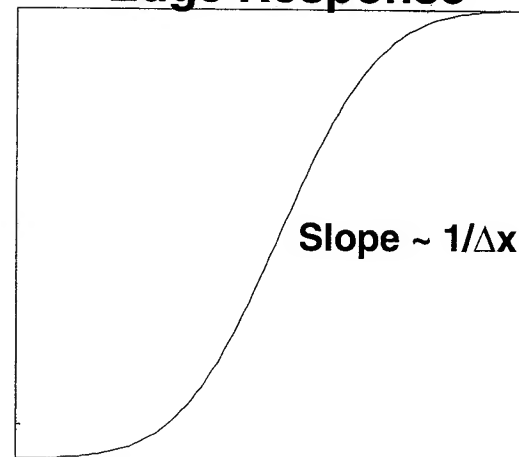
Point Spread Function



Edge



Edge Response



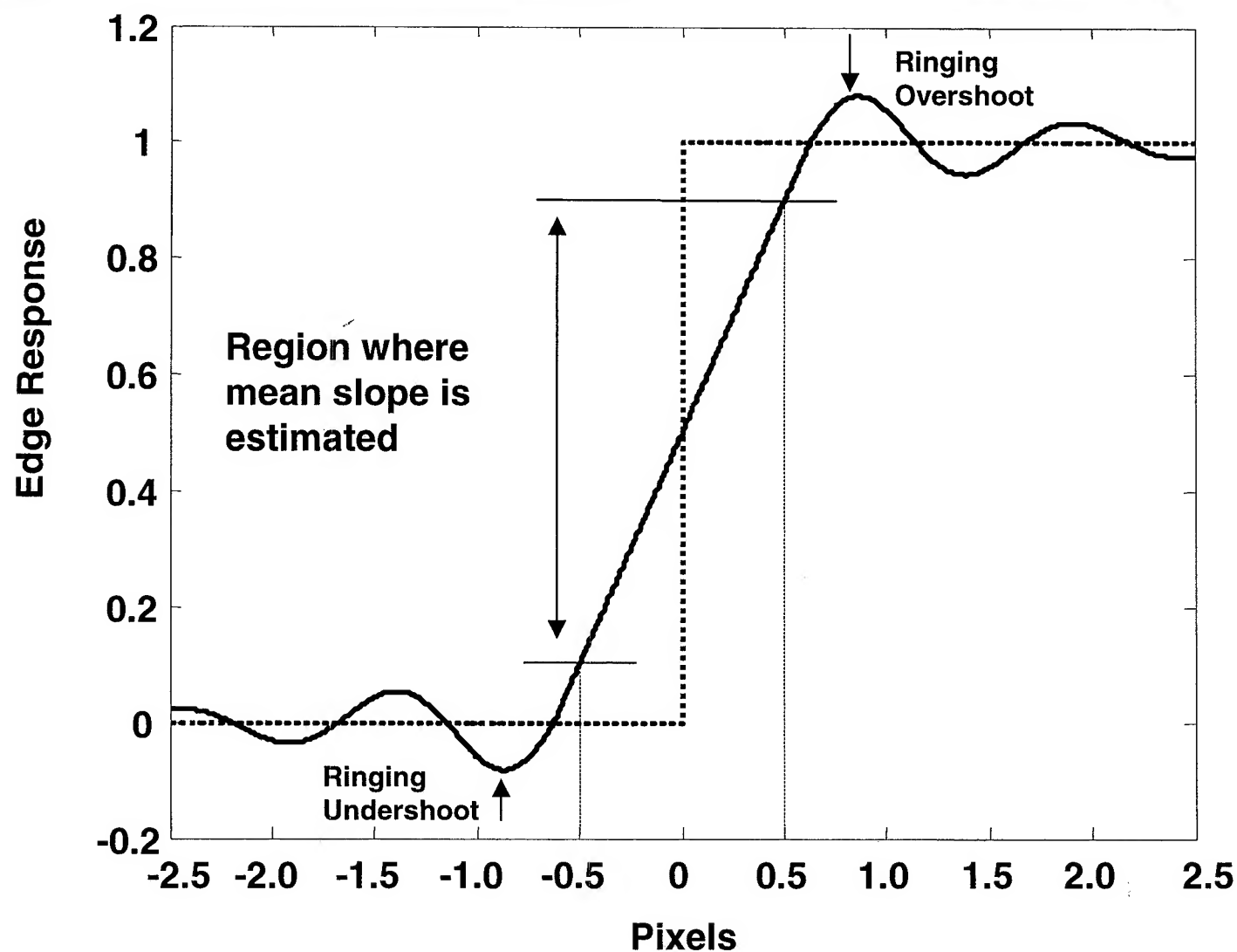
**Steepness of edge response effects spatial resolution**

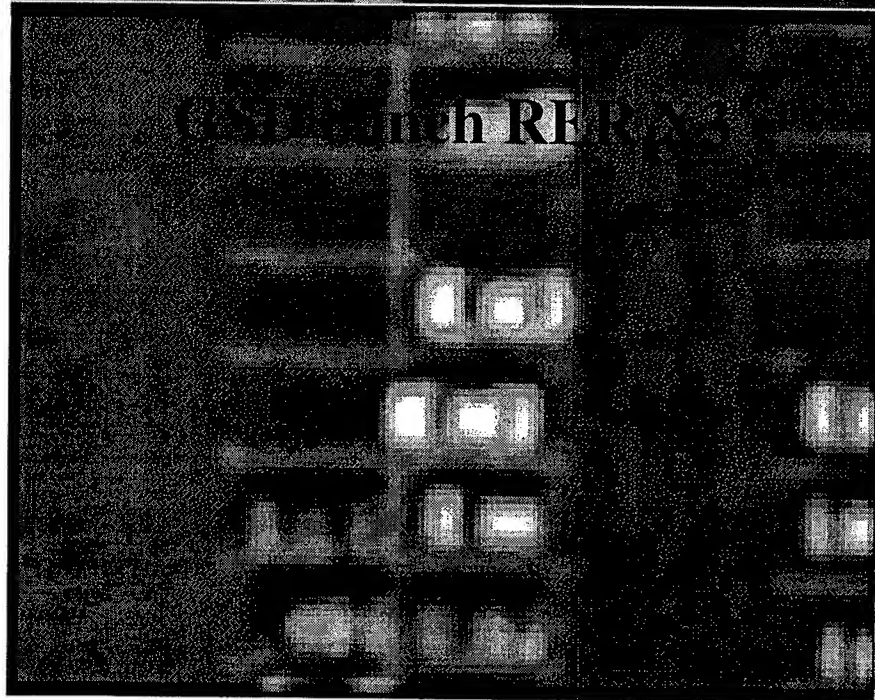
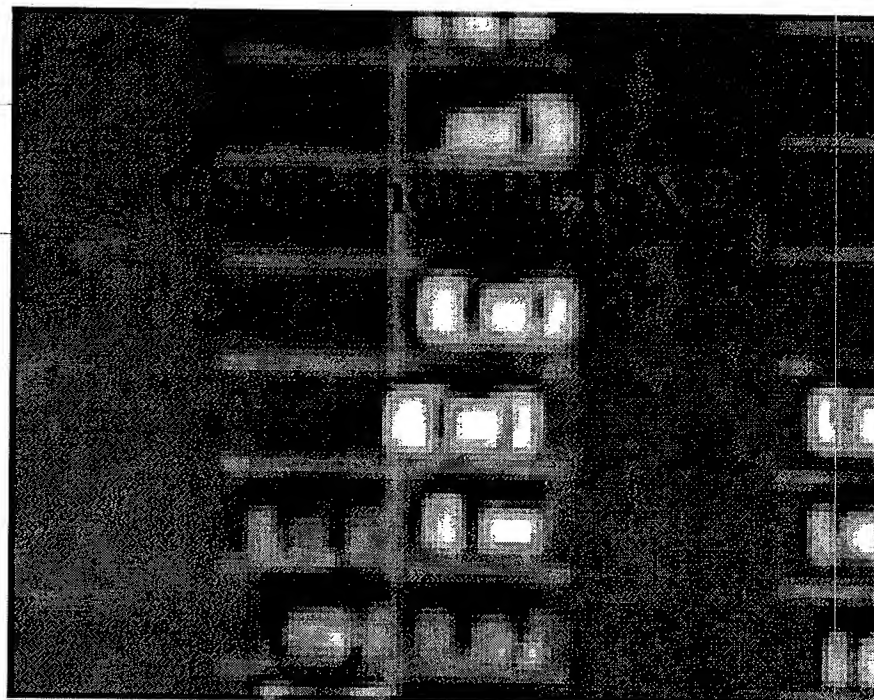
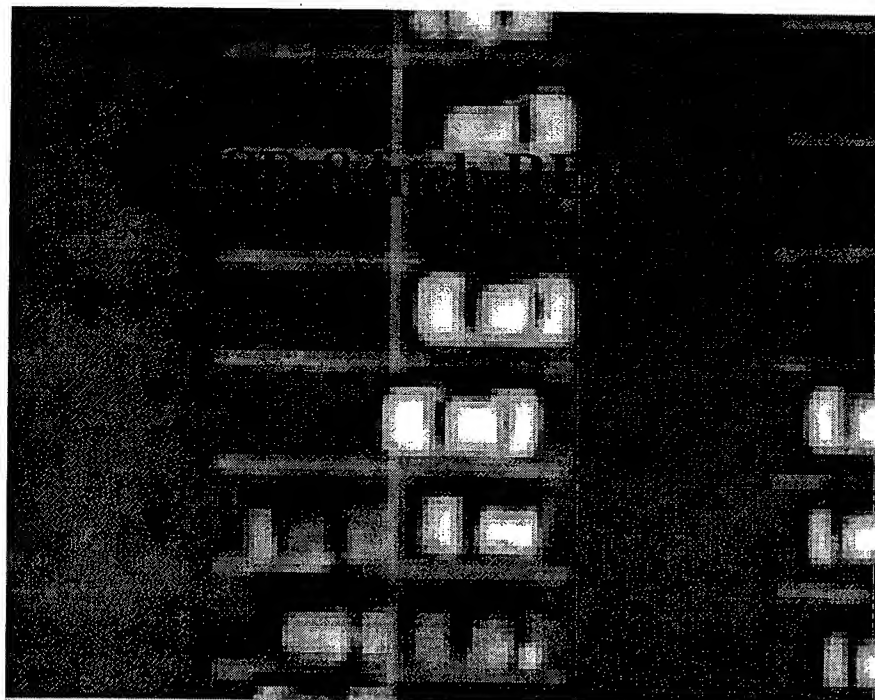




# Spatial Resolution: Relative Edge Response

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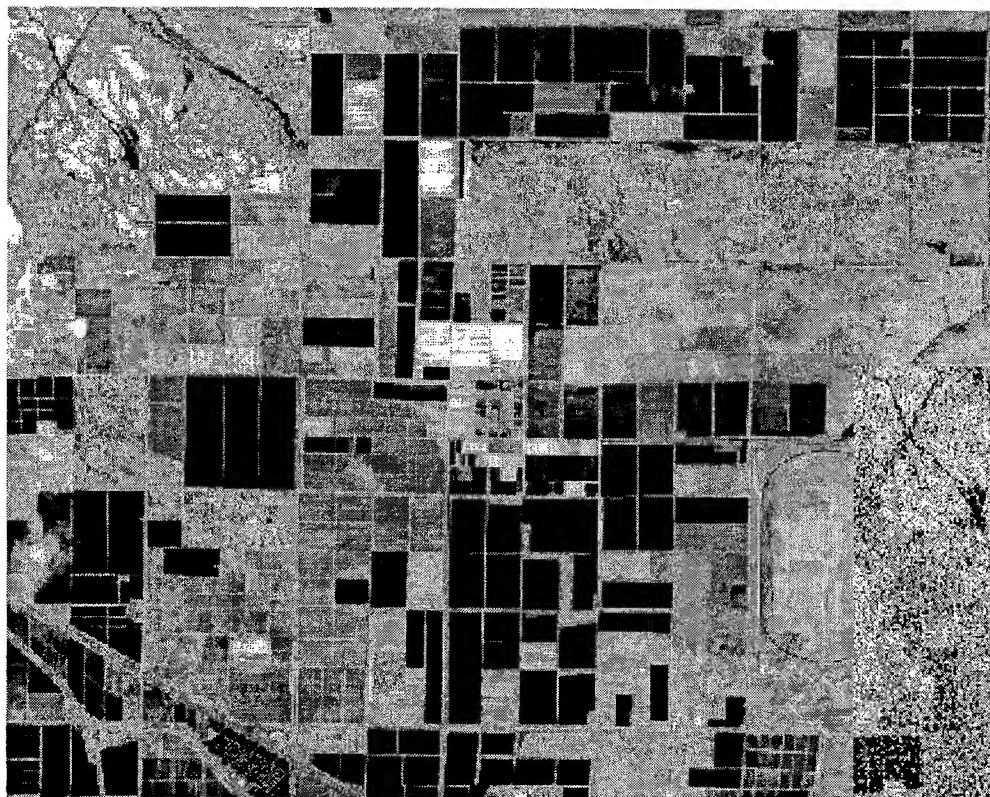






# Spatial Resolution: SNR

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← Original Maricopa IKONOS  
Imagery  
SNR ~ 100

Maricopa IKONOS Imagery  
with Noise Added →  
SNR ~ 2





# Radiometry Specification

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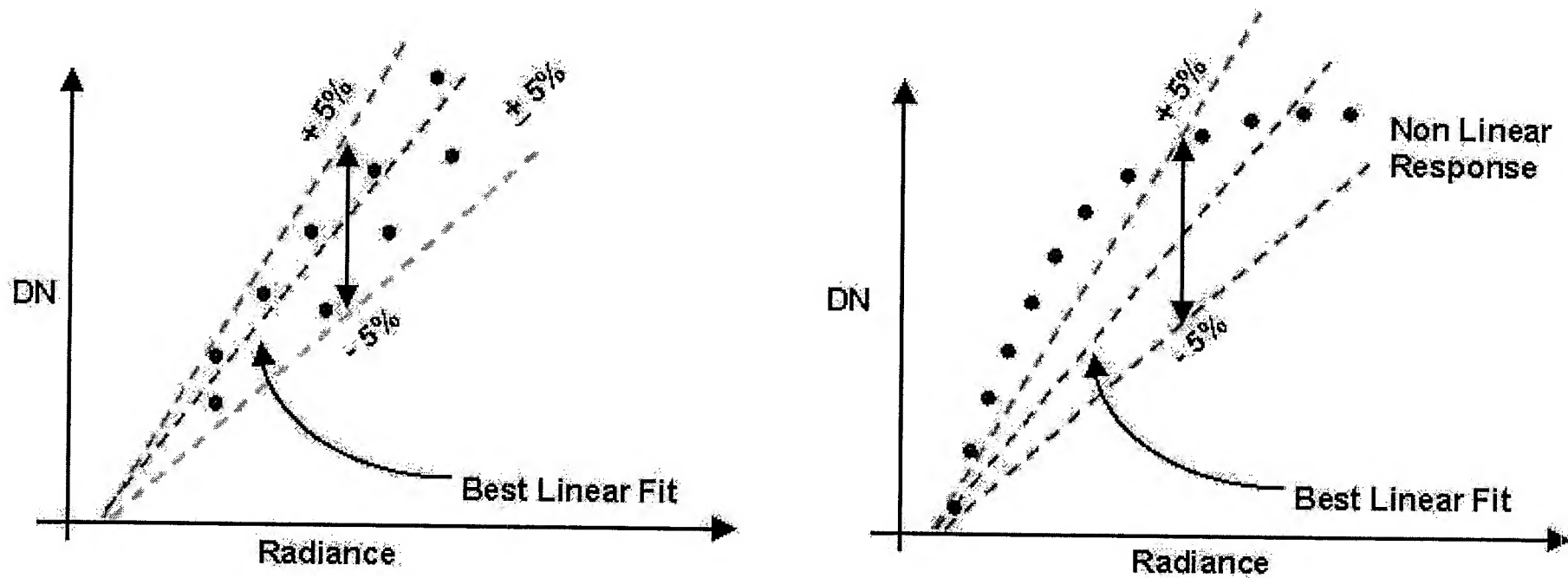
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- **Three Types**
  - Linearity
  - Relative
    - Pixel-to-Pixel
    - Band-to-Band
  - Absolute



# Radiometry: Linearity

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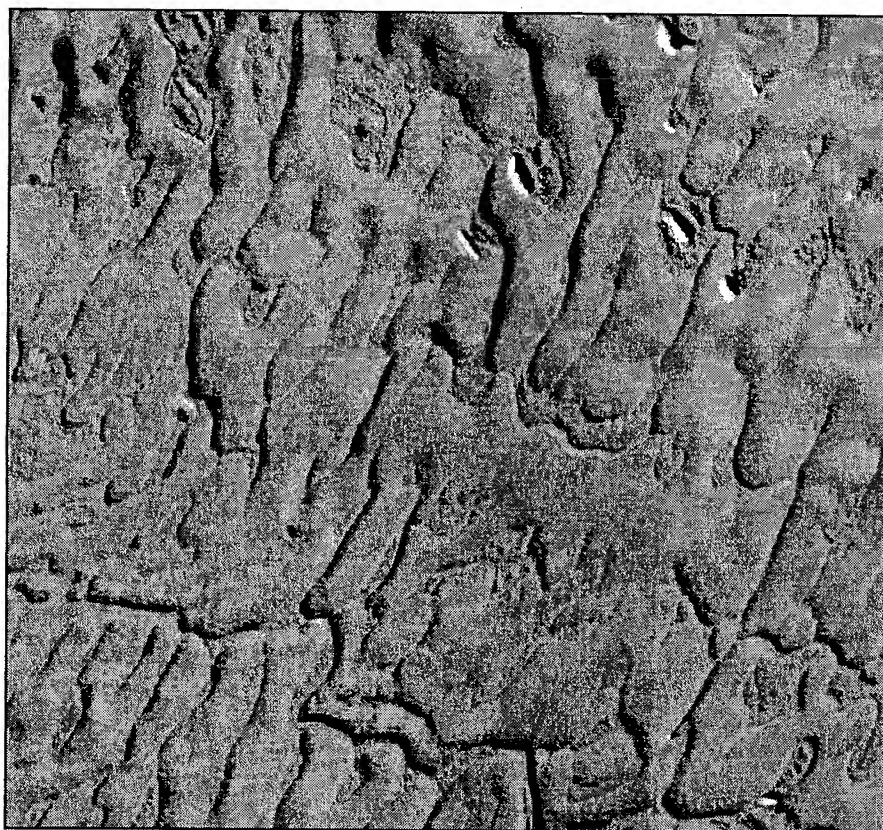
Linear and non-linear response to input radiance





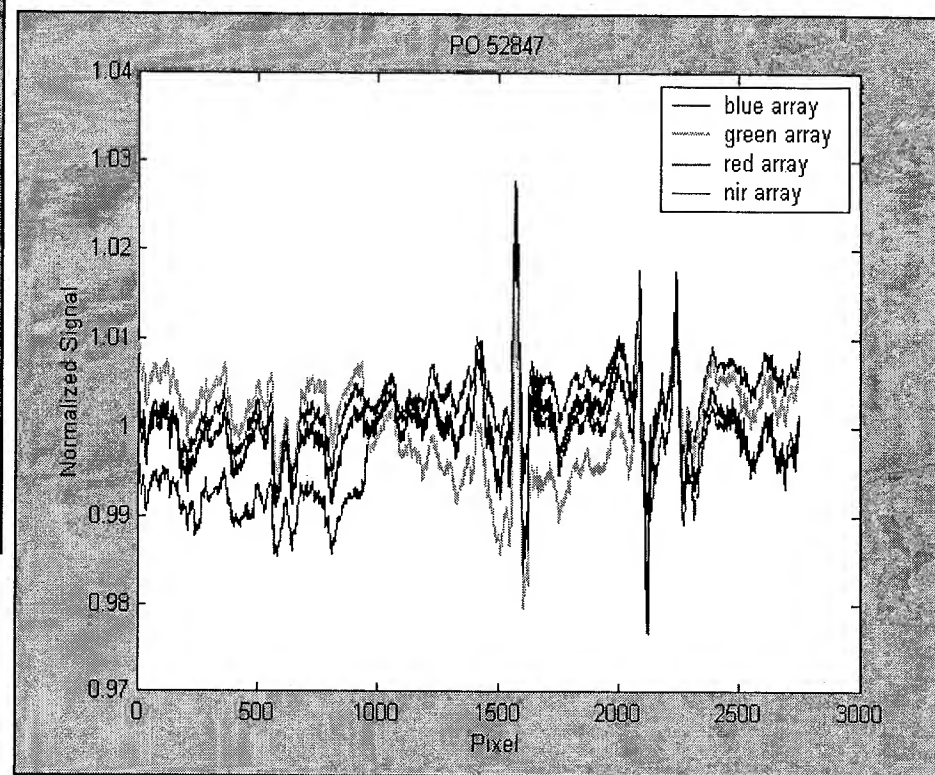
# Radiometry: Relative

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IKONOS Image of Antarctica – RGB, POID 52847

Normalized Average Row Values for Antarctica

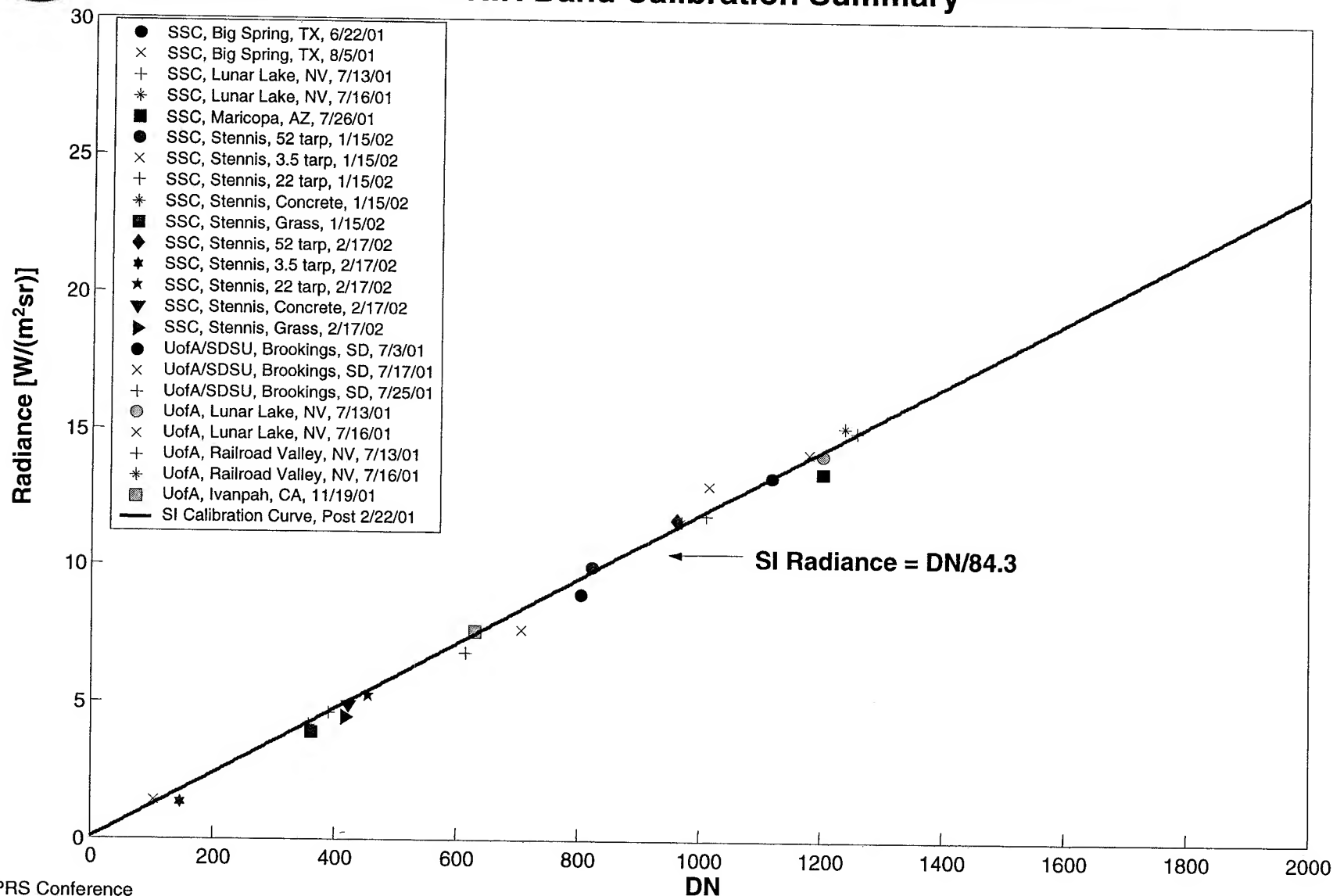




# Radiometry: Absolute

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## NIR Band Calibration Summary



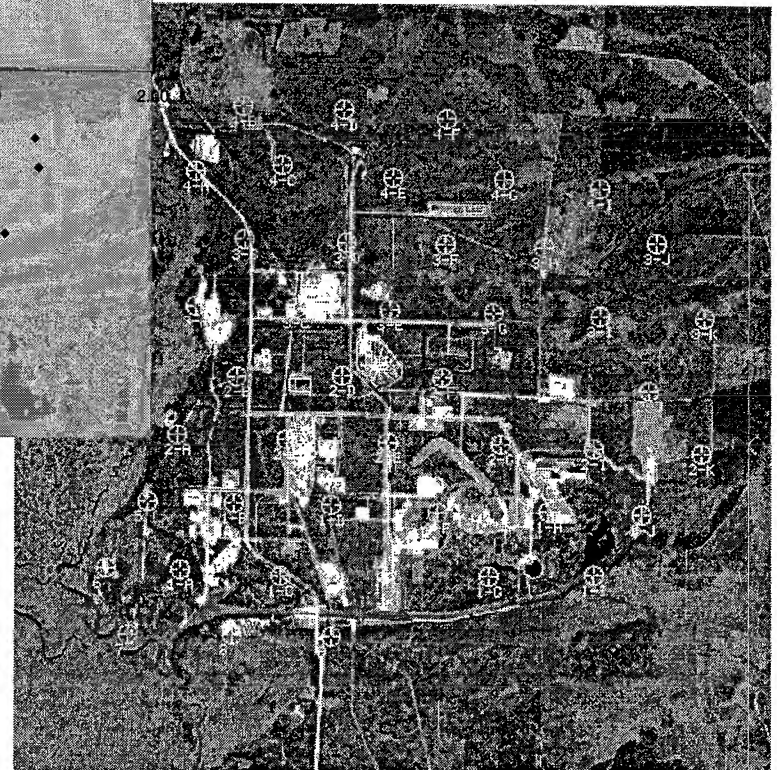
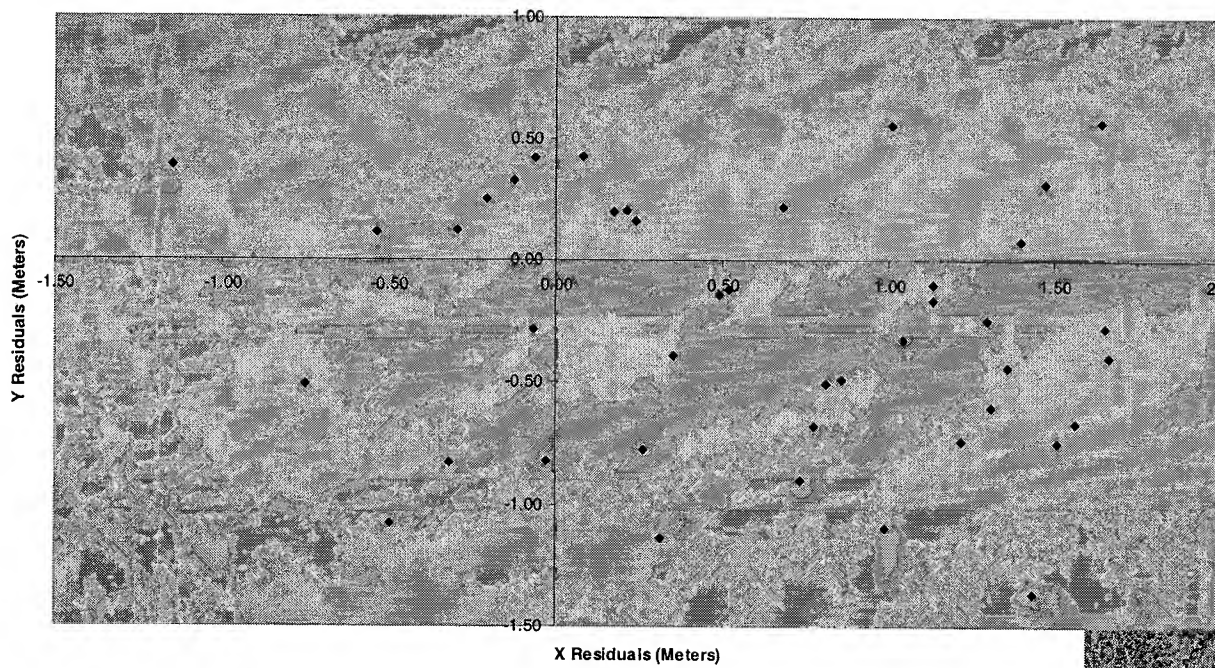


# Geolocalational Accuracy

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- Geolocation of Pixels

SSC Point Residuals Plotted







# Data Product Characterization

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## Data Product Specifications

- Spectral
- Spatial Resolution
- Radiometry
- Geometry



# Laboratory vs. In-Flight: Spectral

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Item	Specification	Verification	
		Lab	Functional (In-Flight)
<b>Spectral Band Information</b>	– Spectral band pass (Blue) 450-515 nm	X	
	– Spectral band pass (Green) 525-605 nm	X	
	– Spectral band pass (Red) 630-690 nm	X	
	– Spectral band pass (NIR) 750-860 nm	X	
<b>Spectral Band Pass Accuracy</b>	– Band edge points at 50% peak response shall be within $\pm 15$ nm of the normal values	X	
	– Slope through the 50% point shall be at least 15% per 20 nm	X	
	– Out-of-band filter response must be less than 5% of the total integrated transmittance within 5% of the transmission points of the band	X	



# Laboratory vs. In-Flight: Spatial

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Item	Specification	Verification	
		Lab	Functional (In-Flight)
<b>Spatial Resolution and Image Quality (at all field angles)</b>	At zero spatial frequency, for all spectral bands, the SNR will be greater than 70 for a Lambertian surface with 20% reflectance, illuminated at solar zenith angle of 30 degrees	X	X



# Laboratory vs. In-Flight: Radiometry

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Item	Specification	Verification	
		Lab	Functional (In-Flight)
<b>Radiometric Accuracy Stability</b>	– Absolute radiometric accuracy to within <del><math>\pm 10\%</math></del>	*	X
	– Relative radiometric accuracy to within <del><math>\pm 5\%</math></del>	*	X
	– Linearity to within $\pm 5\%$ of full scale exposure over the entire imaging exposure dynamic range	X	X
	– Requirements on banding, streaking, failed and non-calibrated detectors: 99.5% of all the detectors should be within $\pm 5\%$ or $\pm 1$ DN of the mean dark counts of all focal plane array detectors; 99.5% of all the detectors should be within $\pm 5\%$ of the gain coefficients of all focal plane array detectors	X	X
		NA	NA
<b>Radiometric Quantization</b>	8-bits per spectral channel	X	X



# Laboratory vs. In-Flight: Geometric

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Item	Specification	Verification	
		Lab	Functional (In-Flight)
<b>Absolute Geolocational Accuracy</b>	Frame center point coordinate referenced to $\pm 100$ meters in metadata listing		X



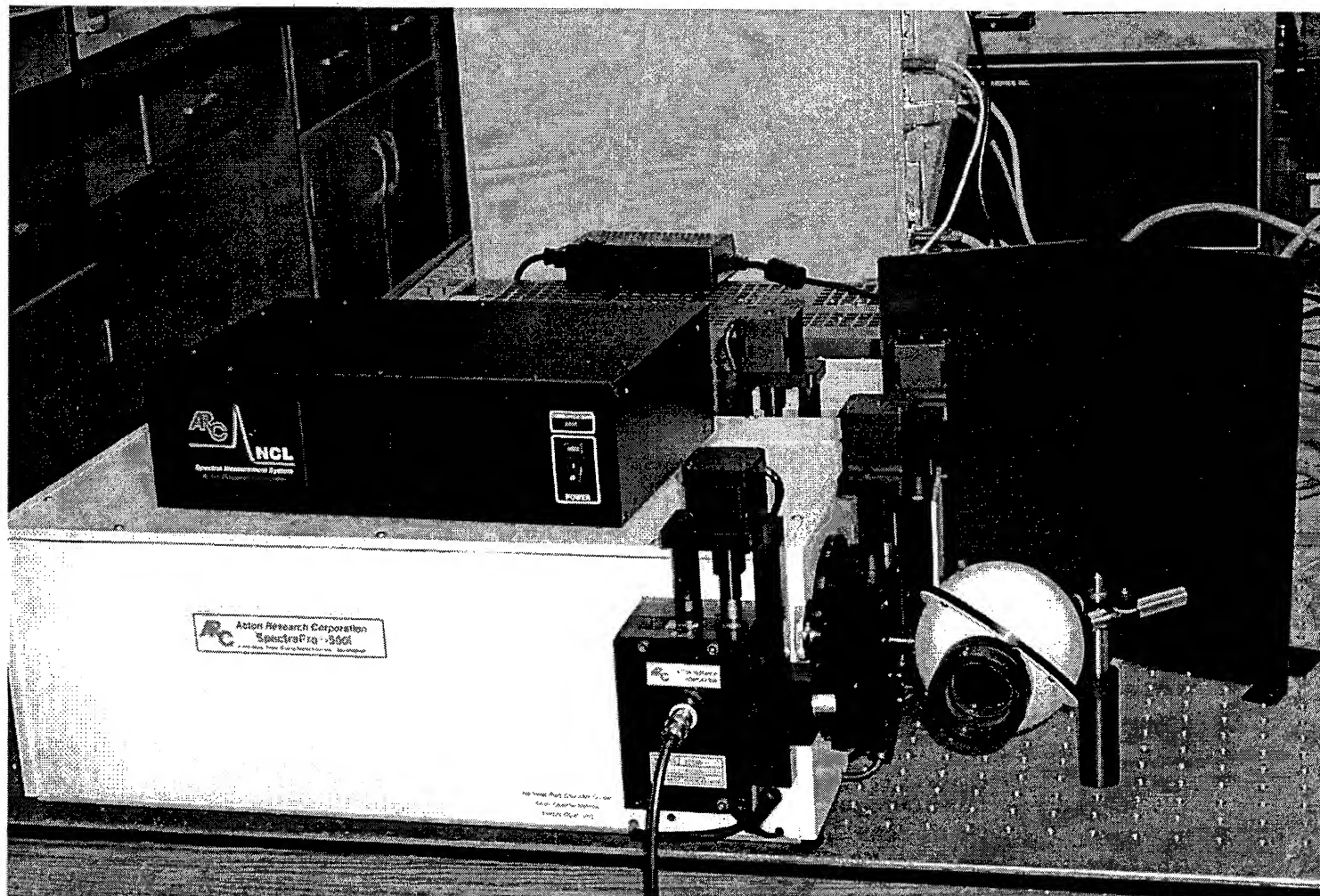
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# Laboratory Characterization



# Spectral Characterization

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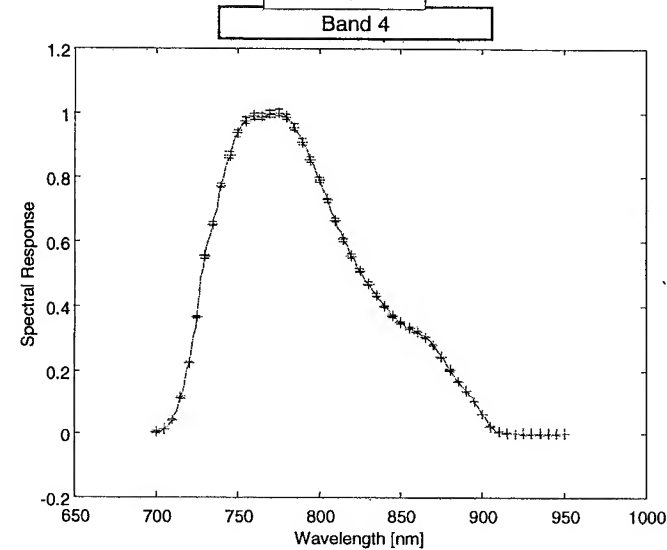
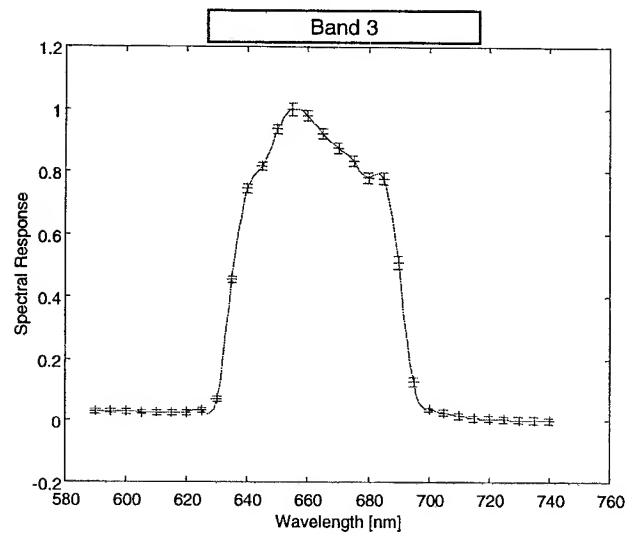
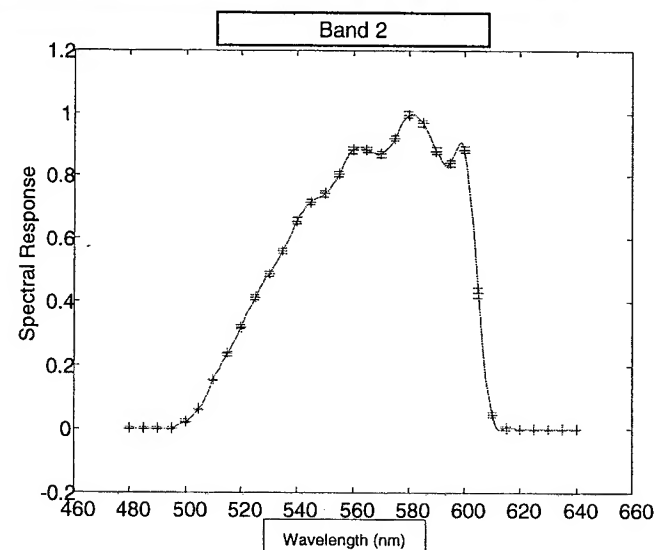
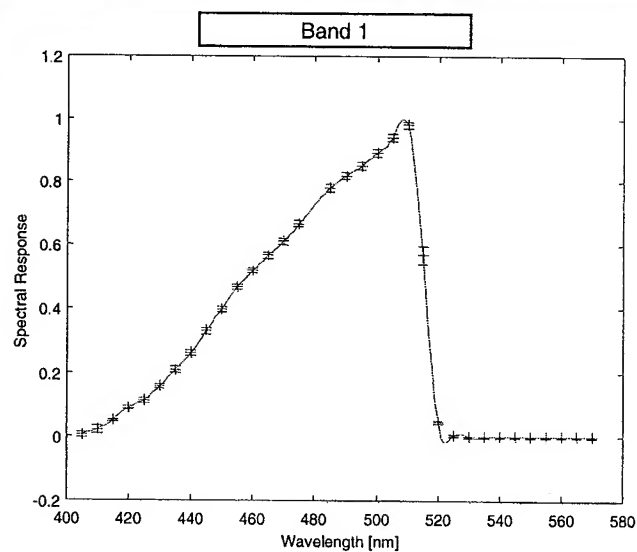


Test setup for overall system spectral response



# Spectral Characterization

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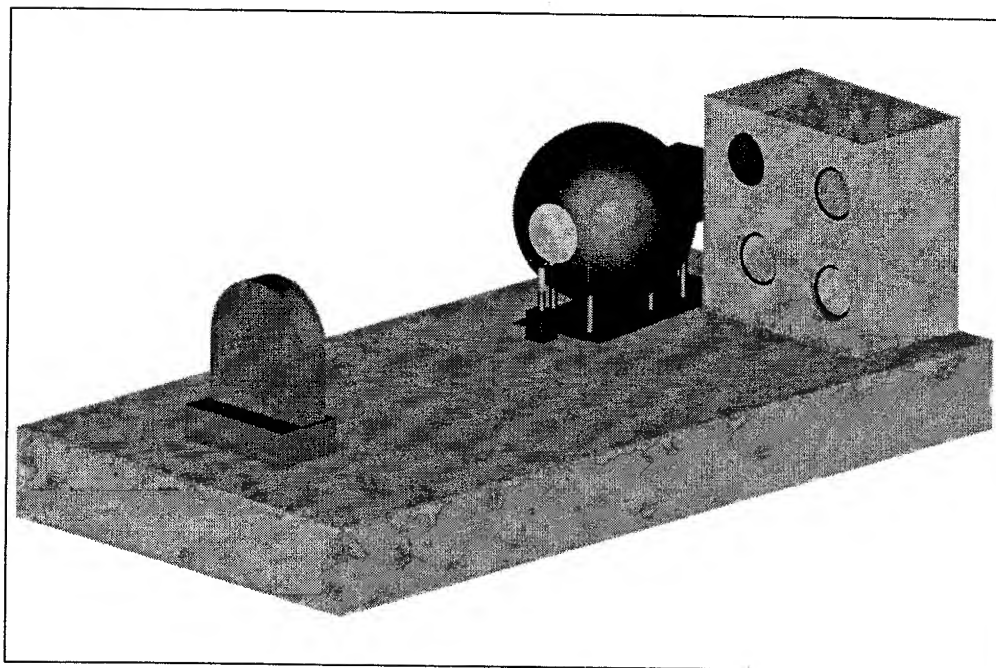
Normalized spectral response functions. Measured points are shown with error bars. Lines show spline interpolation between the points.





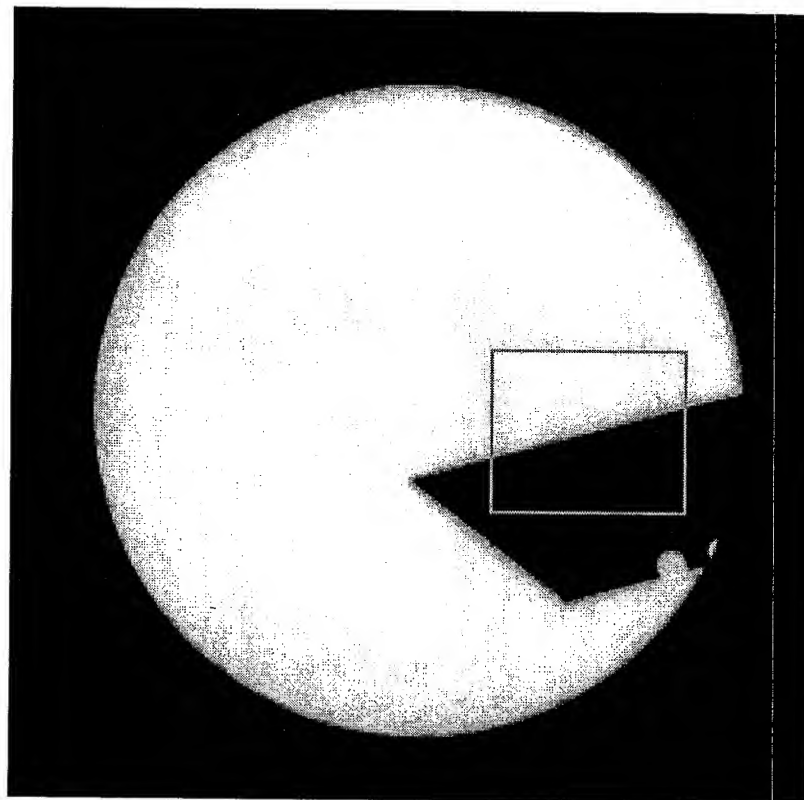
# Spatial Characterization

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**MTF test setup looking at the edge target in a collimator**

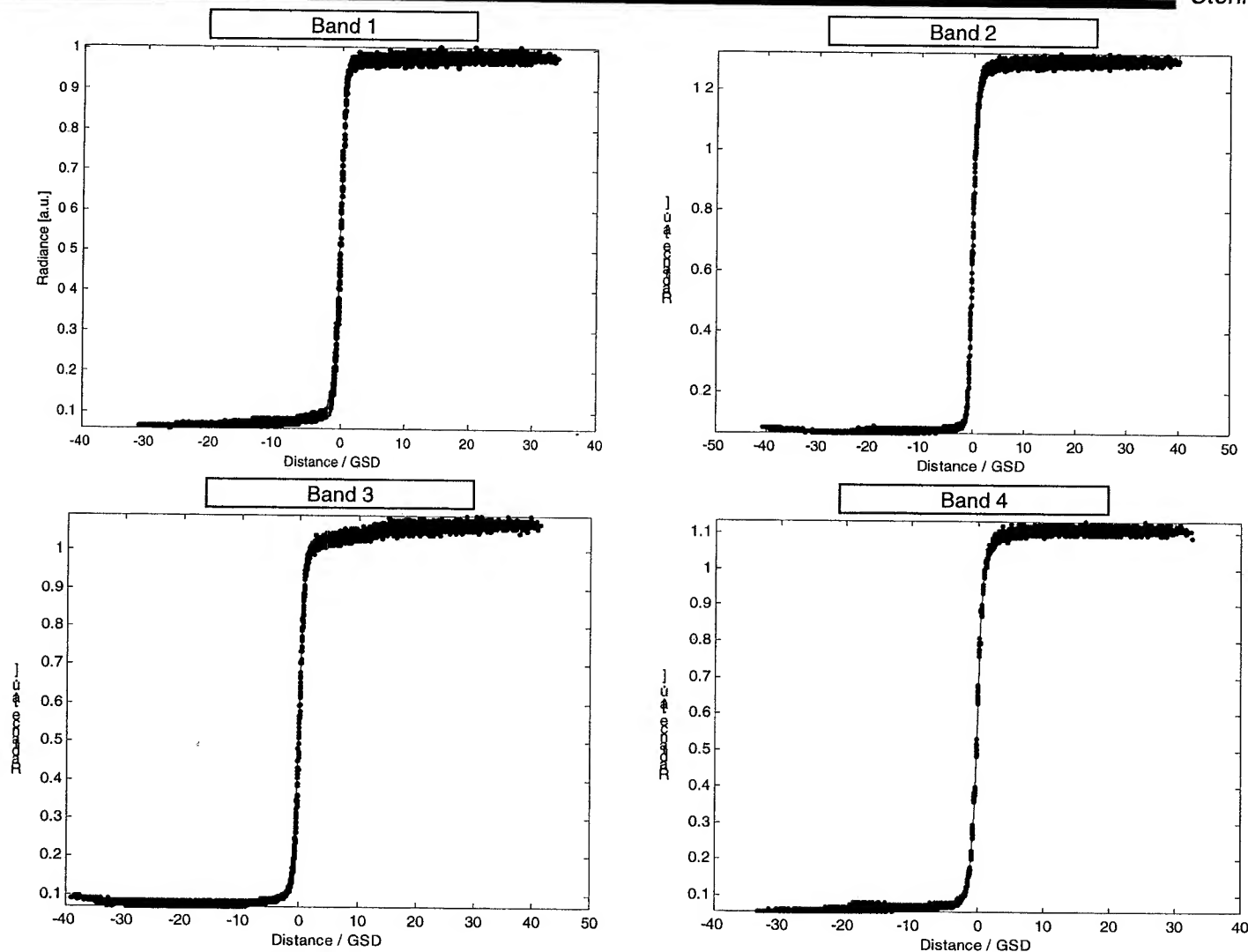
**Fragment of a Blue-band image from tests of spatial resolution of the ADAR 5500 SN4 sensor**





# Spatial Characterization

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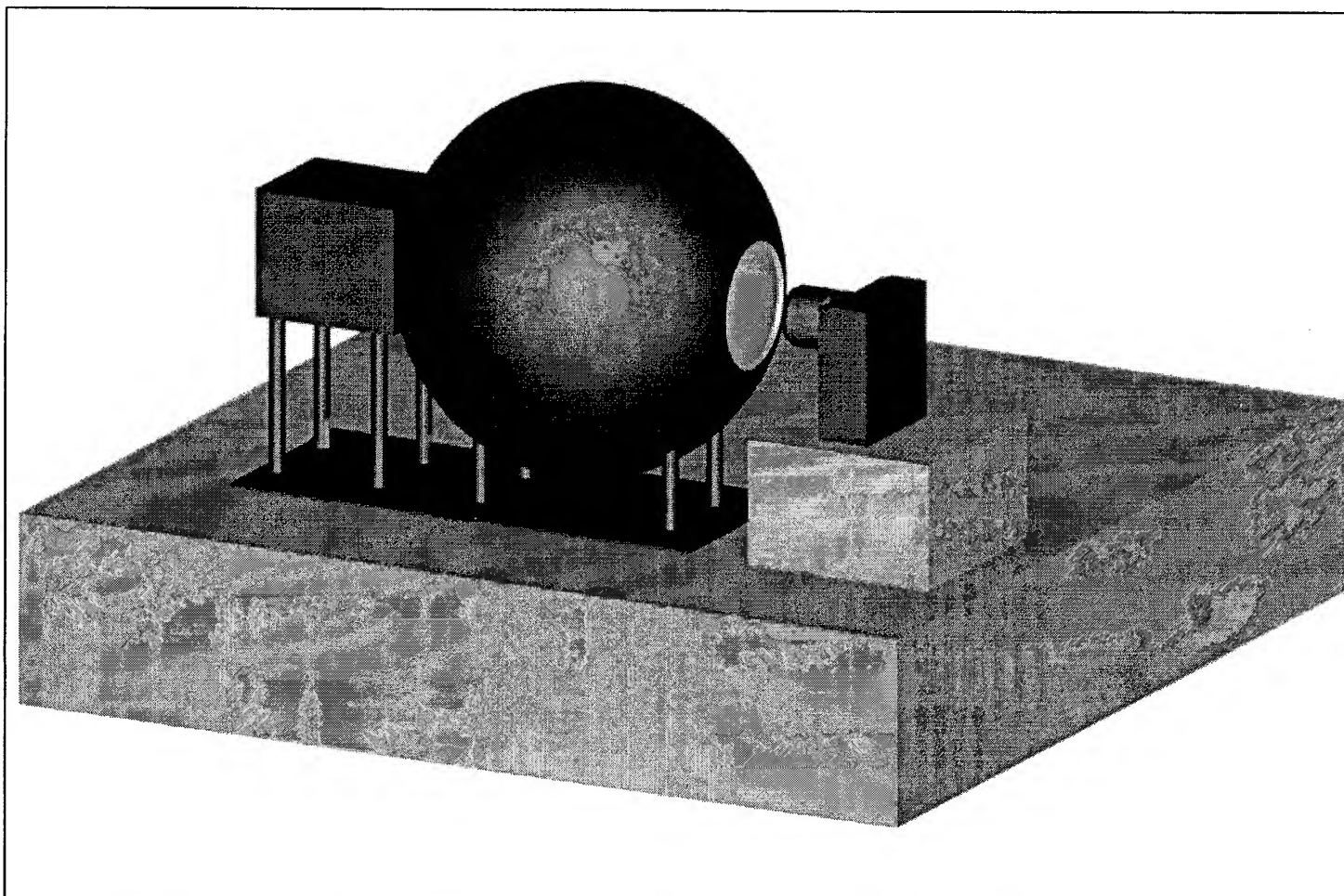


Examples of edge response functions. Measured points are shown with circles.  
Solid lines show the overall fitted functions.



# Radiometric Characterization

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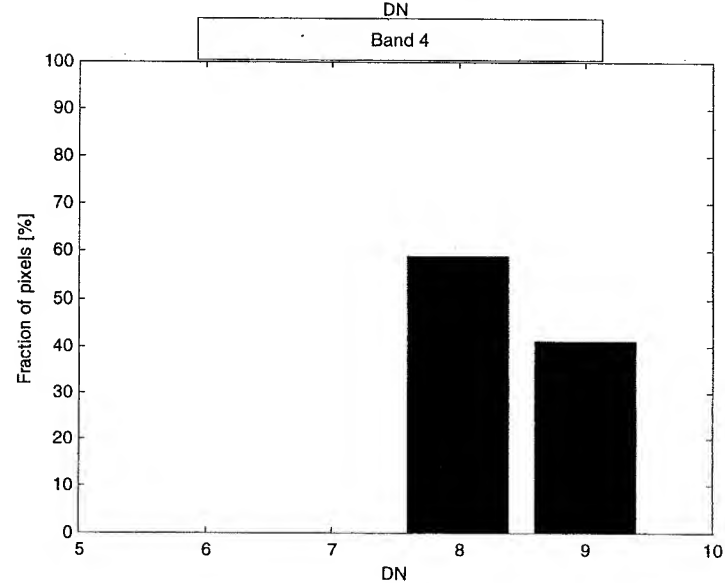
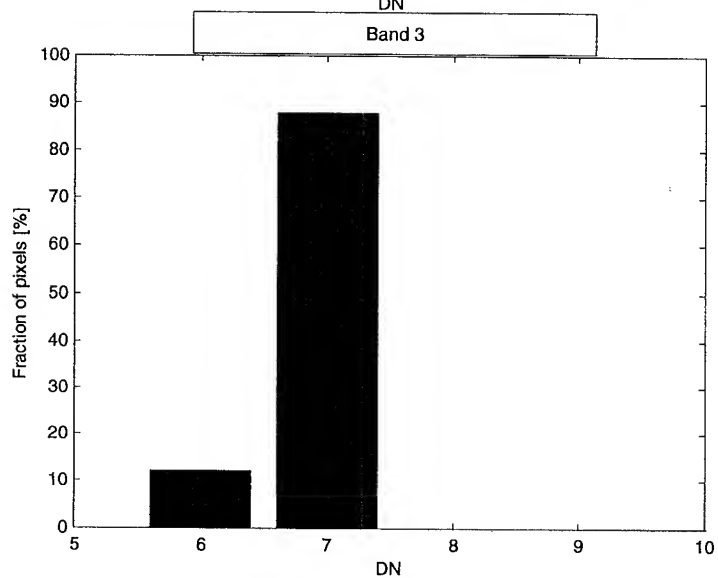
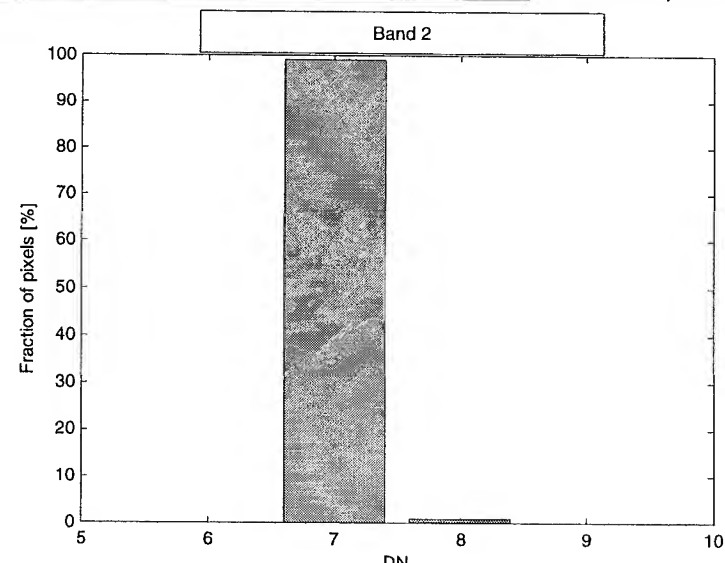
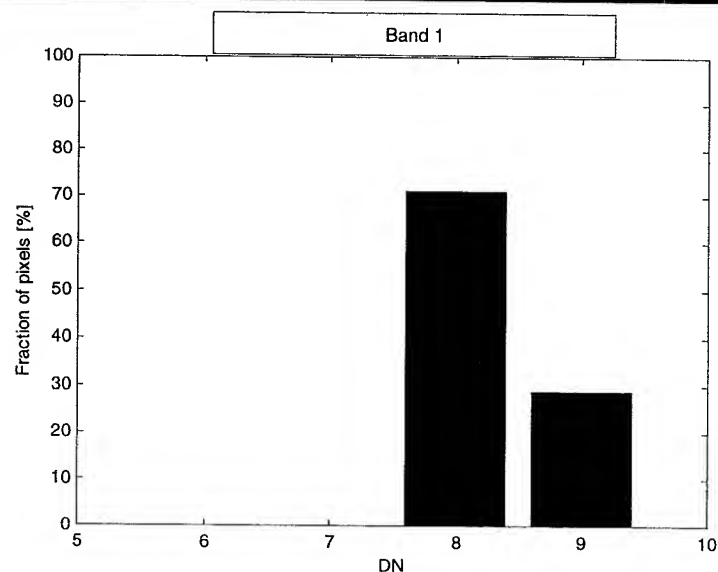


**Radiometric, signal-to-noise, and linearity test setup**



# Radiometric Characterization: Dark Frame Analysis

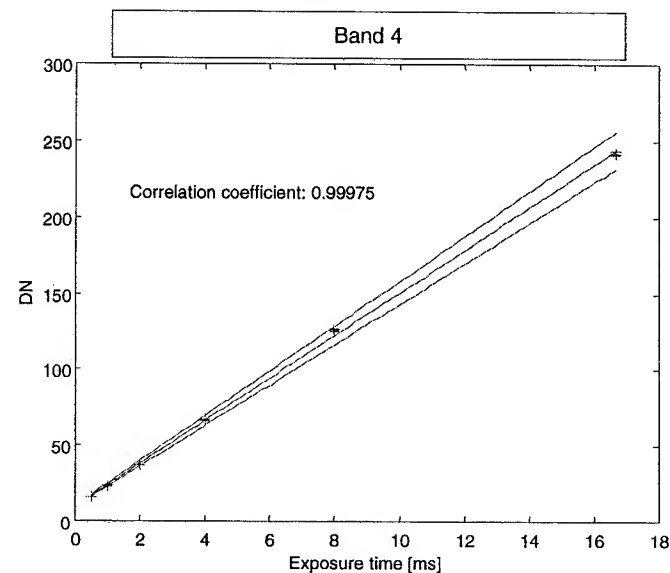
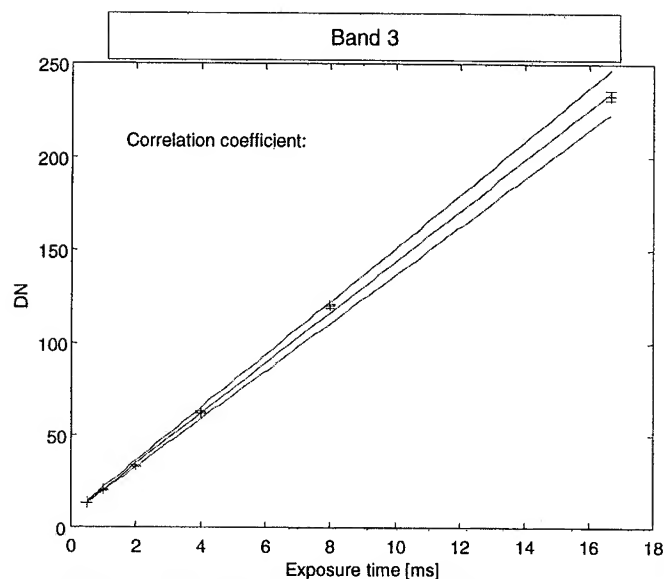
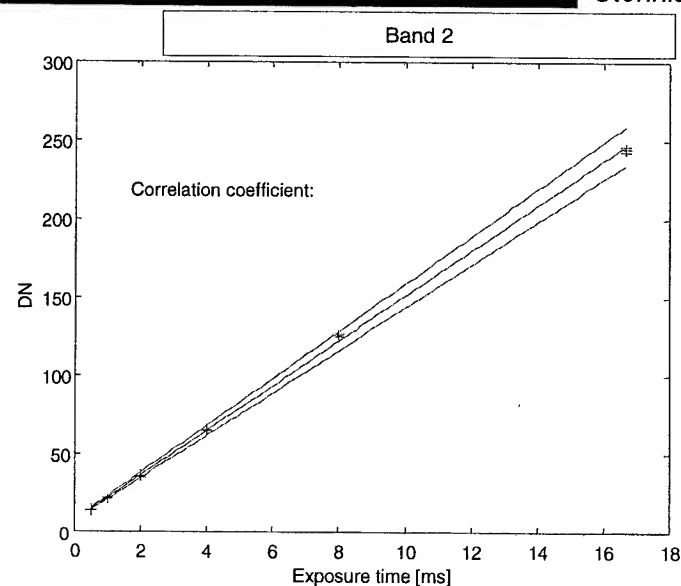
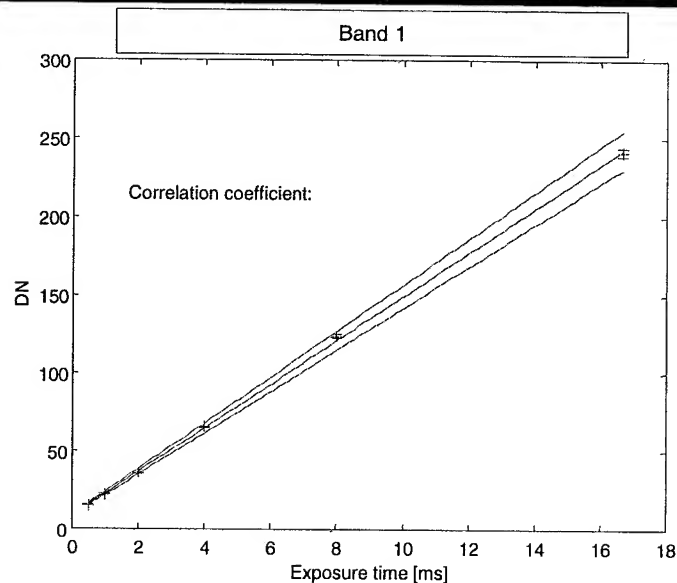
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# Radiometric Characterization

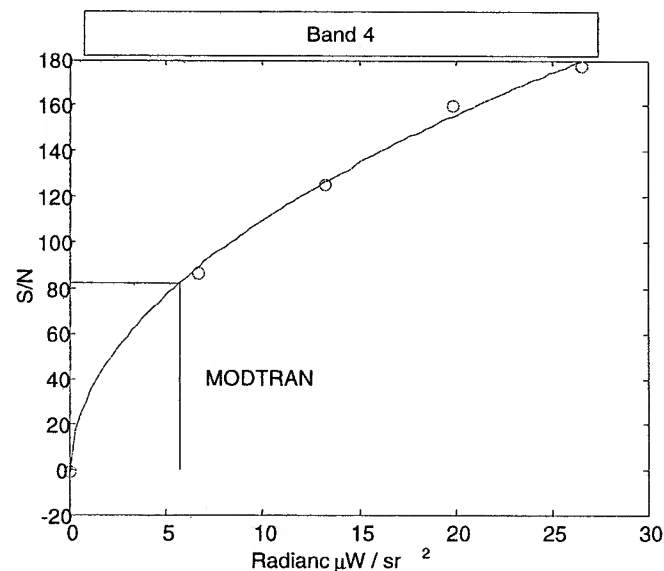
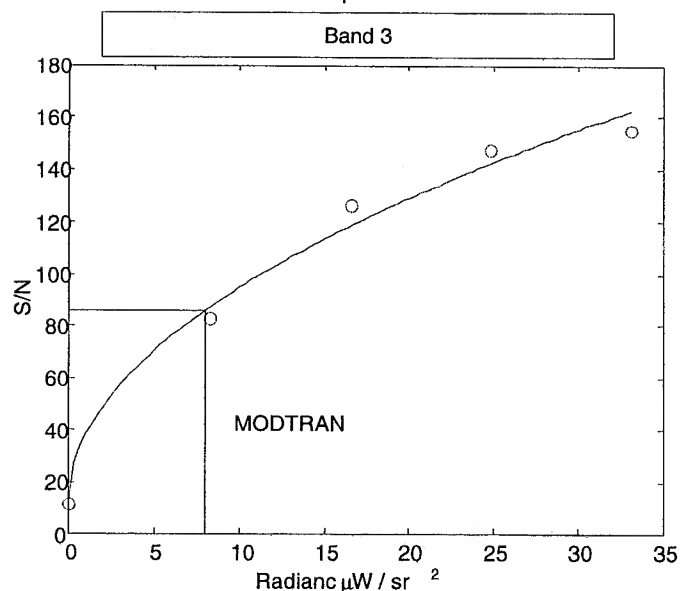
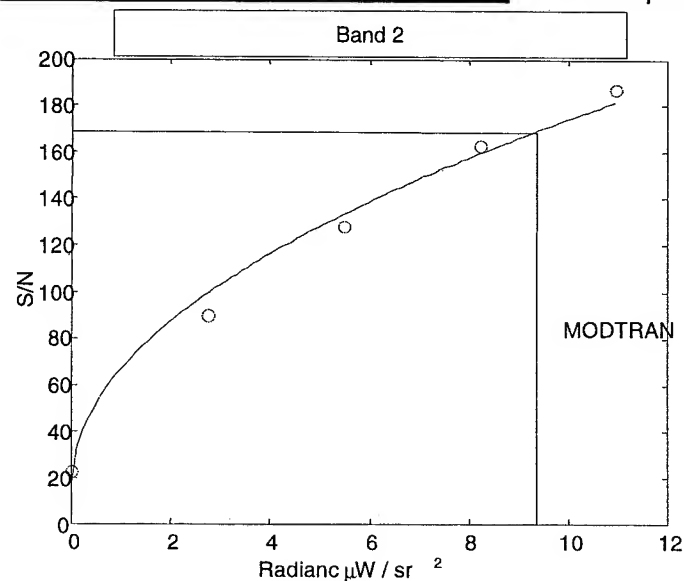
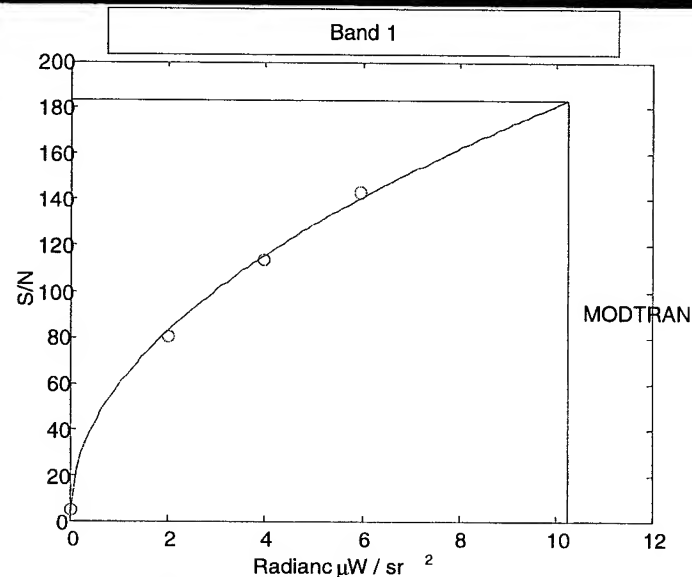
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# Signal-to-Noise

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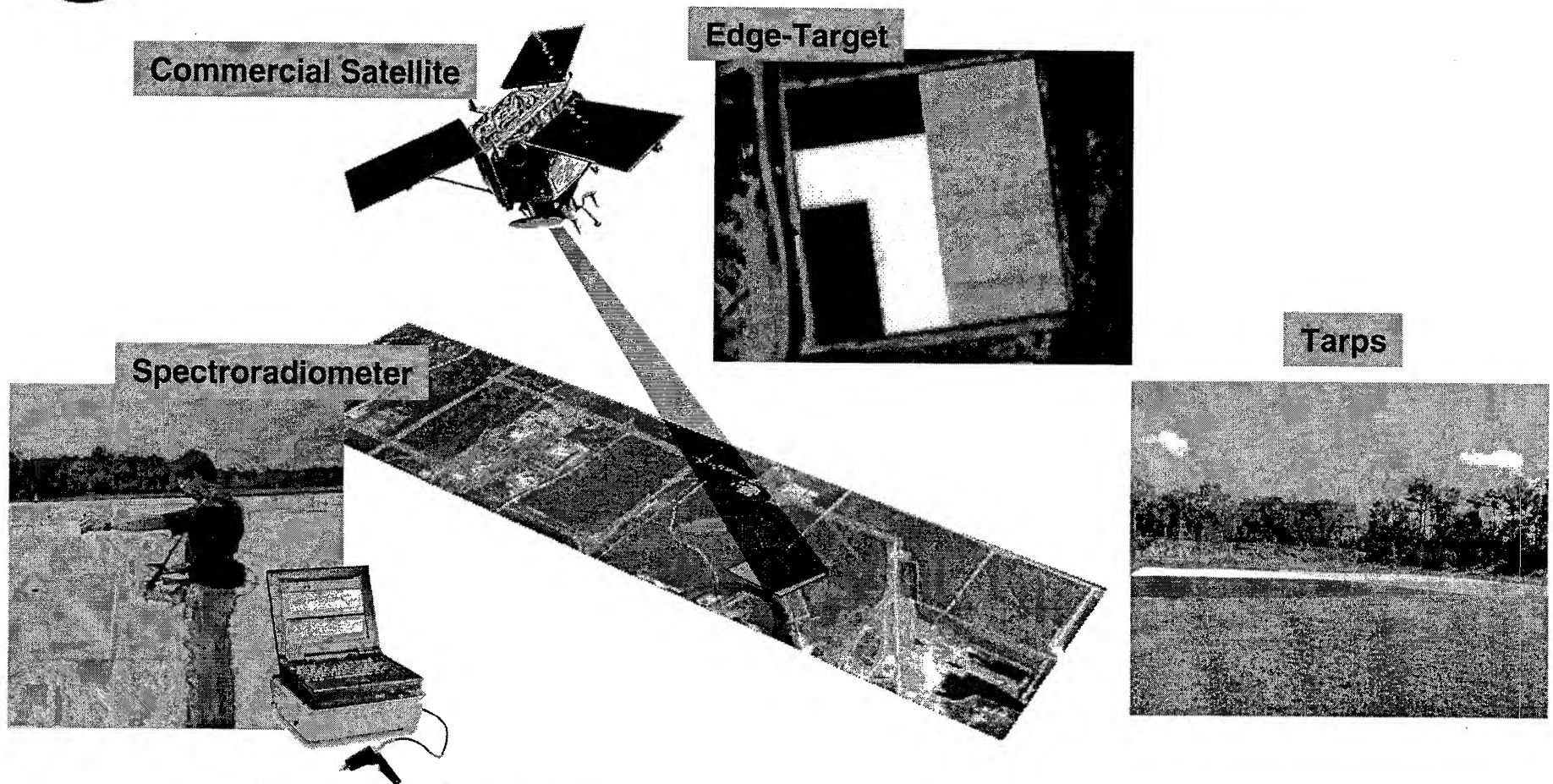


# **In-Flight Characterization**



# Spatial Characterization

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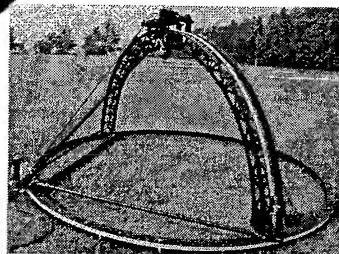
**Method:** Utilize edge targets (tarps, SSC concrete edge target or other man-made features such as painted runways or buildings) and ground reflectance measurements (spectroradiometer) to determine the edge response of remote sensing systems.



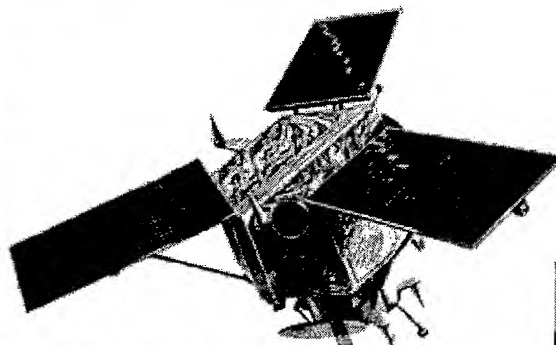


# Radiometric Characterization

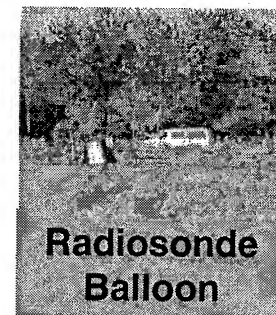
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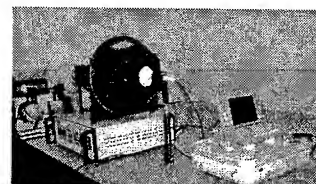
Goniometer



Commercial Satellite

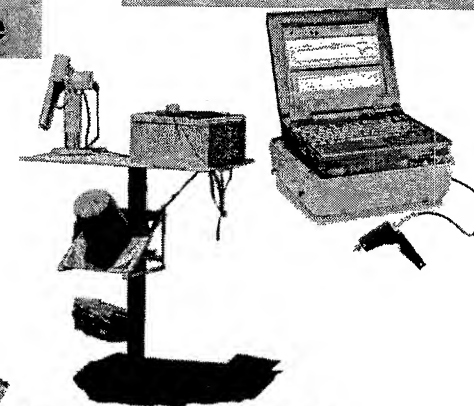


Radiosonde Balloon

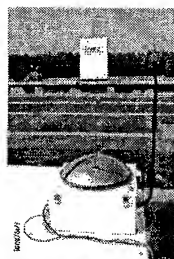


Integrating Sphere

Spectroradiometer



Sun Photometer



Full Sky Imager



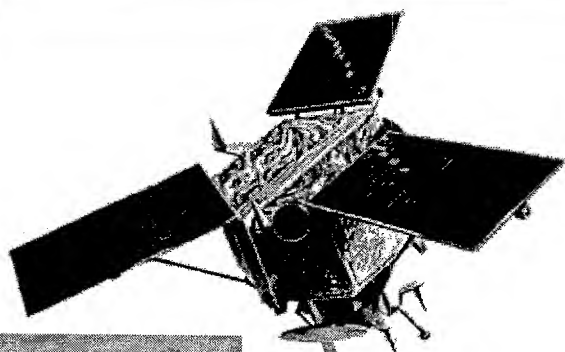
Tarps

**Method:** Utilize ground reflectance measurements (Spectroradiometer) and atmospheric measurements (Sun Photometer & Radiosonde) to determine radiometric accuracy of remote sensing systems.



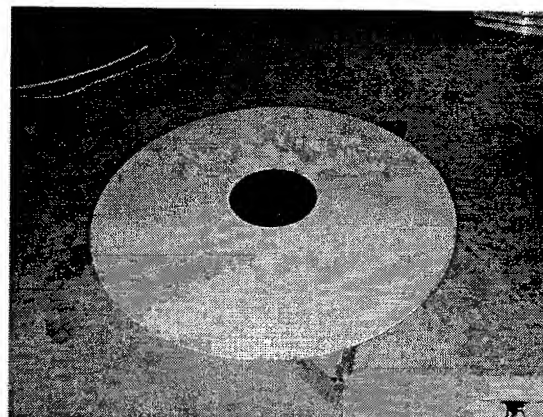
# Geometric Characterization

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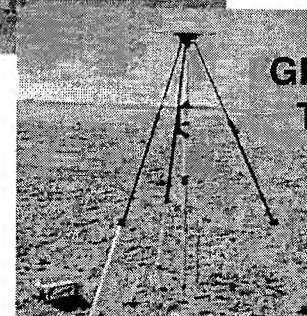


Commercial Satellite

Geodetic Targets



GPS Instrument  
Trimble 4000



**Method:** Utilize geodetic targets and GPS instrumentation to determine the geo-positional accuracy of remote sensing systems.



# Summary

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- **Characterization of digital camera systems is important for supporting digital imagery guidelines**
- **Specifications are characterized in the lab and/or the field**
  - Laboratory characterization is critical for optimizing and defining performance
  - In-flight characterization is necessary for an end-to-end system test

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